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on the electricity-generation sector**

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## Abstract

This article considers the evidence for threshold effects in the relationship between electricity and emission permit prices in France and Germany during the second phase of the EU ETS. Specifically, we compare linear and nonlinear threshold models of electricity prices using Hansen's (2000) approach of sample splitting and threshold estimation. We find evidence of nonlinear threshold effects in both countries. The estimated carbon price thresholds are 14.94€ and 12.57€ in France and Germany, respectively. In Germany, the carbon price does not affect the electricity price below this threshold. In France, the price of emission allowances affects the cost of electricity generation only below the carbon-price threshold, thus revealing speculative behavior by French electricity producers on the carbon-allowance market. This is not the case for German electricity producers.

## Résumé

Cet article explore la présence d'effets de seuil dans la relation liant le prix de l'électricité à celui des permis d'émission en France et en Allemagne pendant la seconde phase du SCEQE. Plus précisément, nous comparons un modèle linéaire de prix de l'électricité avec un modèle non linéaire à seuil en utilisant l'approche de Hansen (2000). Nous montrons que des effets de seuil sont présents dans les deux pays. Les seuils de prix du carbone estimés sont de 14.94€ et 12.57€ en France et en Allemagne, respectivement. En Allemagne, le prix du carbone n'affecte pas le prix de l'électricité en dessous de ce seuil. En France, le prix des quotas d'émission affecte le prix de l'électricité seulement en-dessous du seuil de prix du carbone, révélant ainsi un comportement spéculatif des producteurs d'électricité français sur le marché du carbone. A l'inverse, les producteurs d'électricité allemands ne spéculent pas sur le marché des quotas d'émission.

**Keywords:** Carbon Emission Trading, Energy prices, Nonlinear threshold model.

**JEL classification:** C13 C32 C51 Q49 Q58

## 1 Introduction

The European Union Emission Trading Scheme (EU ETS) is the world's largest emissions permit market to date. It concerns mainly energy and the major industrial emitters. It was set up in two phases: Phase 1, from January 1st, 2005 to December 31st, 2007; and Phase 2 from January 1st, 2008 to December 31st, 2012. Phase 1 is considered as a pilot phase before the introduction of Phase 2, which coincided with the first commitment period of the Kyoto protocol. A third phase was agreed in January 2008 which will start in 2013 and last up to 2020.

Electricity generation is the most polluting activity covered in the EU ETS. As such, we may expect the price of emission permits to impact on electricity prices. Most articles dealing with the relationship

between the price of emission allowances and electricity prices have appealed to linear models (OLS, VARs, VECM, etc.). Sijm *et al.* (2005, 2006) use OLS to determine the fraction of the carbon price that is reflected in electricity prices in Holland and Germany. Honkatukia *et al.* (2008) consider the long- and short-run dynamics of electricity, gas and coal prices and the price of carbon permits in the Finnish market via a VAR analysis. Bunn and Fezzi (2008) use a vector error correction model with allowances, electricity and gas prices in the United Kingdom (UK), with daily temperatures in London and seasonal dummies as the exogenous variables. More recent work has however suggested that the impact of the carbon price on electricity prices is nonlinear and depends significantly on the country's energy mix. Kirat and Ahamada (2011) and Ahamada and Kirat (2012) consider the impact of carbon trading on electricity prices in France and Germany during both phases of the EU ETS: 2005-2007 and 2008-2012.<sup>1</sup> They first use a linear model before introducing nonlinearity via a structural change in the carbon spot price series, which break affects the model parameters. With the linear modeling of an economic system or relationship, we impose the same model parameters across different groups and over time. If the parameters are truly those directly characterizing the economic relationship in question, a change in the underlying economic relationship from one state to another can be expressed as a change in the structural parameters of the empirical model. Econometrically, one way to take into account changes in the structure of parameters is to test for parameter instability in regression and time-series models. There is a fundamental debate over the presence of nonlinearity due to structural change and that due to a threshold effect. We can think of the structural change model (changepoint model) as a special case of the threshold model if we imagine time as the threshold variable. There is a substantial literature dealing with threshold models (see Hansen, 2011). Among these, Hansen (2000) develops a statistical theory for threshold estimation in the regression context and asymptotic distribution theory for the regression estimates.

This article compares a linear model of electricity prices, as in Kirat and Ahamada (2011), to a nonlinear threshold model using Hansen's (2000) approach of sample splitting and threshold estimation. Testing for threshold effects depending on the price of carbon is of primary importance in the context of electricity-price models including the carbon price as a regressor. The model that we propose will allow us to see whether there exists a carbon price at which the behavior of electricity producers changes. We focus on the French and German electricity markets during the Kyoto commitment period of the EU ETS (2008-2012). The results below reject the null hypothesis of linearity in favor of the alternative of a nonlinear threshold effect in both countries. They also reveal speculative behavior by French electricity producers on the carbon market.

The paper is organized as follows. Section 2 sets out Hansen's method applied to the electricity-price

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<sup>1</sup>The figure in Appendix A1 shows the quantities of electricity produced in both countries from various primary energy sources in 2004 and 2009. The share of each of these describes the energy-source mix in electricity generation. While in Germany more than 50% of electricity is generated using coal and lignite, France produces almost 80% of its electricity from nuclear energy, with fossil fuels accounting for just 9% to 10%. Moreover, producing electricity from fossil fuel plants is more costly and emits more CO<sub>2</sub> compared to nuclear plants. Consequently, the electricity and carbon price relationships may be different in the two countries.

model in Kirat and Ahamada (2011). Section 3 then presents and discusses the results. Last, Section 4 concludes.

## 2 The threshold regression model

### 2.1 Threshold model

The linear model considered by Kirat and Ahamada (2011) is very close to the following:

$$P_t^{elec} = \alpha_0 + \alpha_1 P_{t-1}^{elec} + \beta P_t^{gas} + \delta P_t^{coal} + \gamma P_t^{carbon} + \lambda_1 T_t + \lambda_2 T_t^2 + \sum_{j=2}^5 \psi_j season_j + \varepsilon_t \quad (1)$$

where  $P_t^y$  is the logarithm of the price of commodity  $y$  in period  $t$ , and  $T$  is the temperature variable. The square of the temperature is included to capture the well-known nonlinear effect of temperature on electricity prices. The seasonal dummies  $season_j$ ,  $j = 1, \dots, 5$ , correspond to the five business days of the week ( $j = Monday, \dots, Friday$ ). This regression can also be written as follows:

$$P_t^{elec} = \beta X_t + \varepsilon_t \quad (2)$$

where  $\beta = (\alpha_0, \alpha_1, \beta, \delta, \gamma, \lambda_1, \lambda_2, \psi_2, \psi_3, \psi_4, \psi_5)$  and  $X_t = (1, P_{t-1}^{elec}, P_t^{gas}, P_t^{coal}, P_t^{carbon}, T_t, T_t^2, season_2, season_3, season_4, season_5)'$ . We look for a possible nonlinear effect of carbon price on electricity prices using the following threshold regression model:

$$P_t^{elec} = \begin{cases} \beta^1 X_t + \varepsilon_t & \text{if } P_t^{carbon} \leq p \\ \beta^2 X_t + \varepsilon_t & \text{if } P_t^{carbon} > p \end{cases} \quad (3)$$

where  $\beta^{(1)} = (\alpha_0^1, \alpha_1^1, \beta^1, \delta^1, \gamma^1, \lambda_1^1, \lambda_2^1, \psi_2^1, \psi_3^1, \psi_4^1, \psi_5^1)$  and  $\beta^{(2)} = (\alpha_0^2, \alpha_1^2, \beta^2, \delta^2, \gamma^2, \lambda_1^2, \lambda_2^2, \psi_2^2, \psi_3^2, \psi_4^2, \psi_5^2)$ . The threshold parameter  $p$  is considered to be unknown. It is convenient to rewrite (3) as follows:

$$P_t^{elec} = \beta^{(2)} X_t + \delta X_t(p) + \varepsilon_t \quad (4)$$

where  $\delta = \beta^{(1)} - \beta^{(2)}$ ,  $X_t(p) = X_t I(P_t^{carbon} \leq p)$  and  $I(\cdot)$  is the indicator function. We want to estimate  $\beta^{(1)}$ ,  $\beta^{(2)}$  and  $p$  if the null hypothesis of linearity is rejected, i.e.  $H_0 : \delta = 0$  in equation (4).

### 2.2 Nonlinearity Tests and Estimation

We first examine the null hypothesis of linearity in equation (4),  $H_0 : \delta = 0$ . Without an *a priori* fixed value of  $p$  in regression (4), it is not easy to make any statistical inference regarding  $\delta$ . In this case  $p$  is a nuisance parameter which is not identified under the null hypothesis. To avoid this problem, Hansen (1996) developed a simulation technique producing a p-value statistic for the inference of  $\delta$ . His approach does not require fixing an *a priori* value of  $p$  and allows for possible heteroskedasticity in (4). The computation method of the threshold estimate  $\hat{p}$  uses the concentrated sum of squared errors function from (4):

$$S(p) = \sum_{t=1}^T \left( P_t^{elec} - \widehat{\beta^{(2)}}(p)X_t + \widehat{\delta}(p)X_t(p) \right)^2 \quad (5)$$

and the threshold estimate  $\widehat{p}$  is the value that minimizes  $S(p)$  :

$$\widehat{p} = \arg \min_{p \in \Gamma} S(p) \quad (6)$$

where  $\Gamma$  is a bounded set of elements of  $\{P_t^{carbon}, t = 1, \dots, T\}$  and can be approximated by a grid (see Hansen, 2000). Finally, the slope estimates in the threshold model (3) can be computed via  $\widehat{\beta^{(2)}}(\widehat{p})$  and  $\widehat{\delta}(\widehat{p})$ . Hansen (2000) also developed asymptotic distribution theory for the threshold estimate  $\widehat{p}$ , and proposed asymptotic confidence intervals by inverting the likelihood-ratio statistic. His approach again allows for possible heteroskedasticity in (4).

## 3 Application

### 3.1 Data

We use electricity prices in €/MWh from the day-ahead base-load<sup>2</sup> contracts covering the French and German markets which are traded on the EPEX spot exchange.<sup>3</sup> Day-ahead contracts are traded on a given day for the delivery of electricity one day ahead. The data we use here are of weekday frequency and run from March 3rd, 2008 to December 30th, 2010. The carbon spot price comes from the Bluenext environmental trading exchange expressed in € per ton. With respect to the primary energy markets, we appeal to the following price series expressed in € per MWh: i) the gas price of the month-ahead future contract traded on the Zeebrugge hub; and ii) the coal price of the month-ahead future contract Coal CIF ARA. The temperature information comes from the European Climate Assessment Dataset,<sup>4</sup> and is calculated as the average temperatures recorded at representative regional weather stations. Our final sample consists of 724 observations.

### 3.2 Results and comments

We first check that there is evidence of a threshold effect associated with the emission permit price. We do so by employing both the F-test to consider a threshold under homoskedastic errors and the heteroskedasticity-consistent Lagrange multiplier (LM) test for a threshold of Hansen (1996, 2000). The p-values of test-statistics for the null  $H_0 : \delta = 0$  (conditional on  $p = \widehat{p}$ ) are computed using a bootstrap with 10000 replications.

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<sup>2</sup>The electricity base-load price is the price on the block for 24 hours. This is an arithmetic average price over the 24 hours of the day (from 0h to 23h).

<sup>3</sup>EPEX Spot exchange is a holding company created by the collaboration between EEX Power Spot and Powernext SA, respectively the German and French electricity stock exchanges.

<sup>4</sup>Klein Tank *et al.*, "Daily dataset of 20th-century surface air temperature and precipitation series for the European Climate Assessment", 2011, available at <http://eca.knmi.nl>.

Table 1: Test results of no threshold against the alternative of a threshold

Assumption regarding errors	Germany		France	
	Homoskedastic	Heteroskedastic	Homoskedastic	Heteroskedastic
Test for no threshold	31.161	25.309	32.269	27.776
	(0.039)	(0.046)	(0.027)	(0.017)

Note: The bootstrapped p-values computed with 10000 replications are in (); The F-test and LM-test are used to test for no threshold under the assumption of homoskedastic and heteroskedastic errors, respectively.

Table (1) and Figures (1) and (2) show the results of these tests of no threshold against the alternative of a threshold effect in both Germany and France. These results strongly reject the null hypothesis of no threshold in favor of the alternative of a threshold at the 95% confidence level in both countries. Figures (1) and (2) plot the F-test statistic as a function of the threshold in the carbon-allowance price in Germany and France, respectively. The dotted lines in the graphs represent the critical values at the standard significance level of 95%. The null hypothesis of linearity is rejected in favor of the alternative of a threshold effect in both countries. Linearity is rejected if the F-test statistic exceeds the critical value. Since the F-test is valid only with homoskedastic errors, it needs to be complemented by an LM test, as in Table (1). We thus consider the threshold-test results which are indicated by the results from the homoskedasticity tests which are shown in the last row of Table (2). Specifically, the relevant threshold tests are the F-test in Germany and the LM-test in France, since we do not reject homoskedasticity in the residuals of the threshold model in Germany but we do so for France.

Figures (3) and (4) show the graphs of the normalized likelihood-ratio statistic as a function of the threshold in the carbon-allowance price (in logs) in Germany and France, respectively. The estimates of the carbon thresholds (in logs) are the values that minimize these graphs, which occur at 2.531 (12.57 €/ton) and 2.704 (14.94 €/ton) in Germany and France, respectively. The dotted lines in the graphs represent the 95% critical values, so we can read off the asymptotic 95% confidence intervals from the graphs where the normalized likelihood-ratio sequence crosses the dotted lines. These confidence intervals (in logs) are [2.5257, 2.5313] in Germany and [2.6925, 2.7555] in France. The corresponding 95% confidence intervals in €/ton are [12.50, 12.58] and [14.77, 15.73], respectively. These results show that there is a reasonable evidence for a two-regime specification in both countries. Figures (3) and (4) show that the confidence intervals are fairly tight, so the uncertainty over the values of these thresholds is correspondingly small.

Table (2) present the estimation results of the threshold model of electricity prices in Germany and France. This table also contains the estimation results from the corresponding linear models in columns (2) and (5), and underlines the irrelevance of inference when nonlinearity is not taken into account. Row (3) shows the estimated threshold  $\hat{p}$  and its 95% confidence interval. The estimated carbon price thresholds are 12.57 and 14.94 €/ton in Germany and France, respectively. These thresholds are significantly different

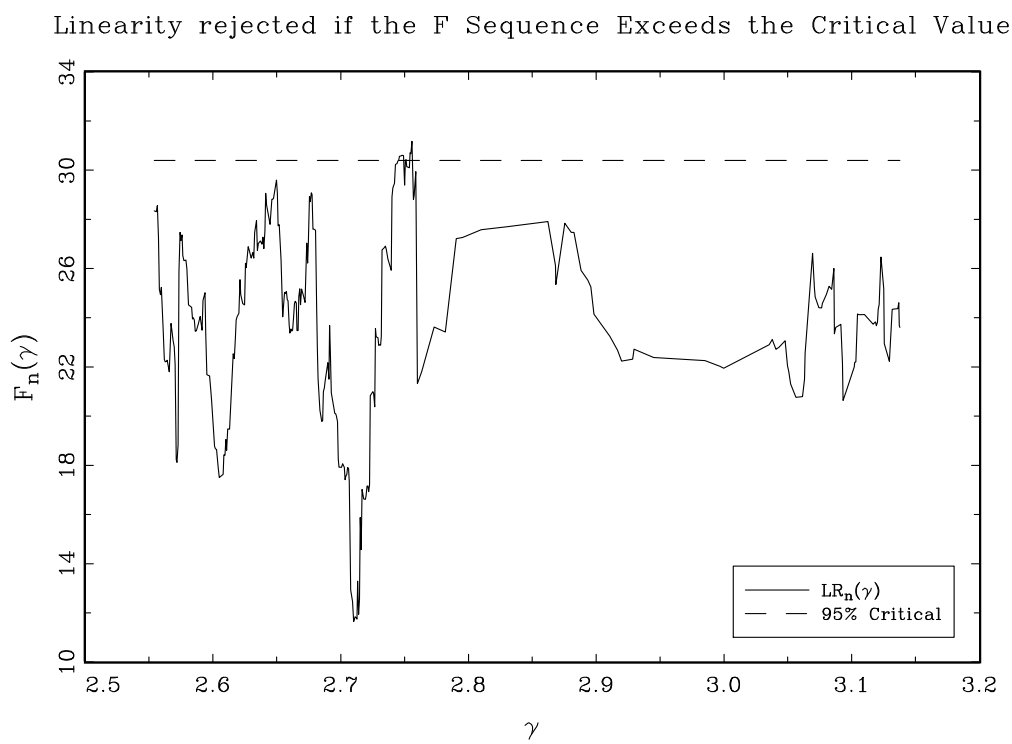


Figure 1: Test for linearity against nonlinearity in Germany

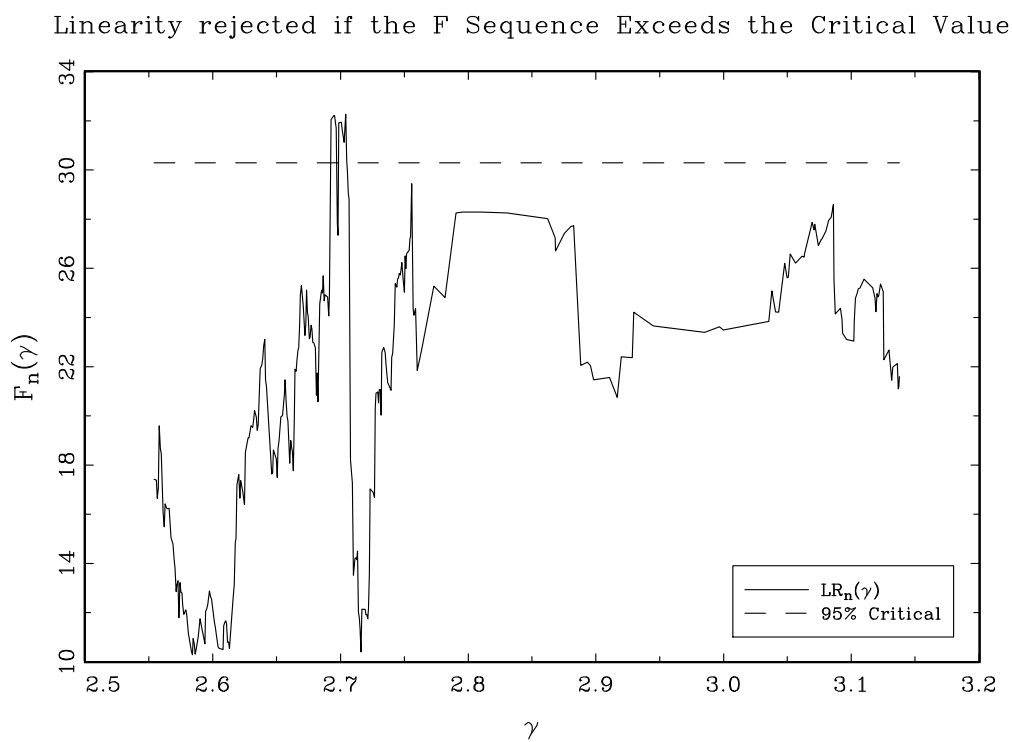


Figure 2: Test for linearity against nonlinearity in France



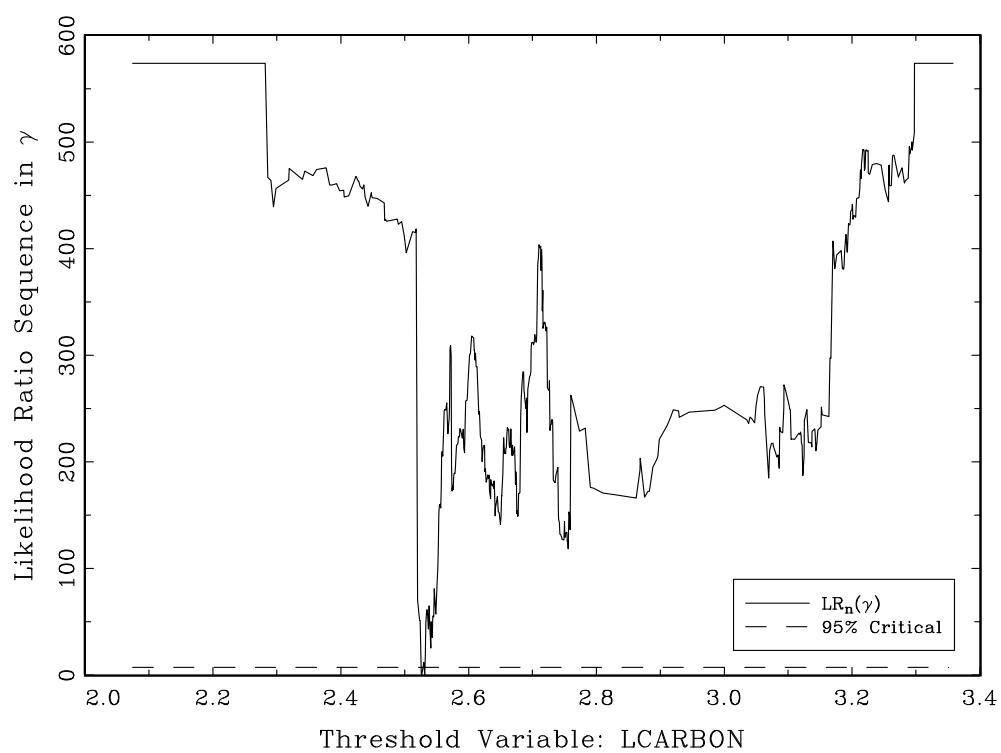


Figure 3: Germany: Confidence interval construction for the threshold (in logs)

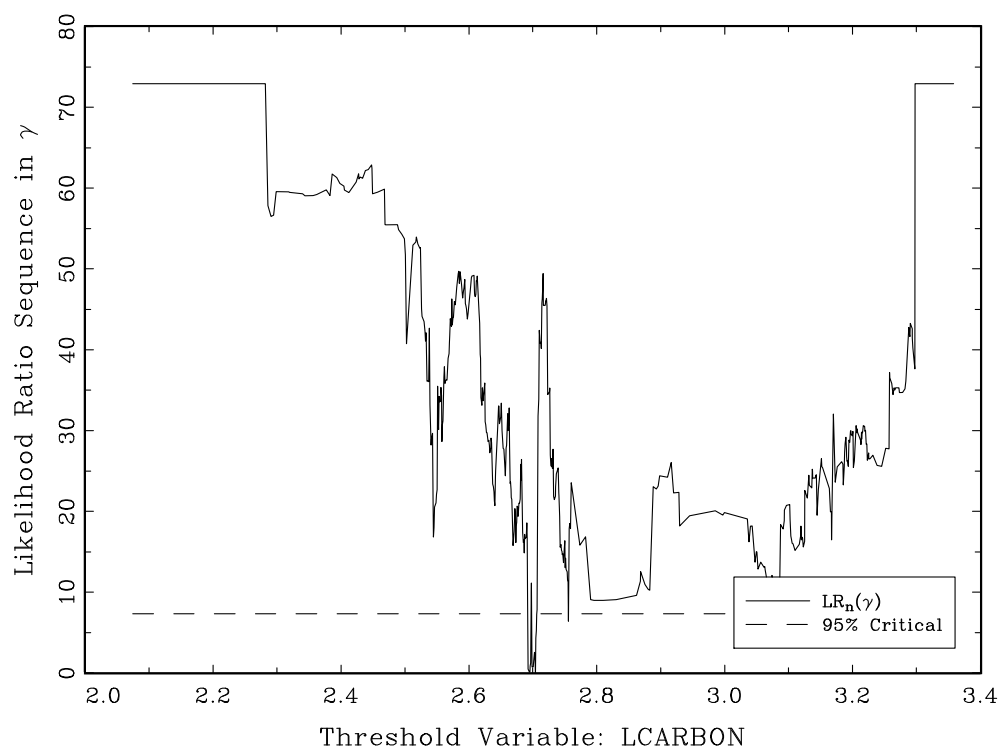


Figure 4: France: Confidence interval construction for the threshold (in logs)

Table 2: Estimation Results

Country	Germany			France		
Threshold ( $\hat{p}$ )	Linearity	Nonlinearity		Linearity	Nonlinearity	
Regime		12.57€ [12.50 ; 12.58]			14.94€ [14.77 ; 15.73]	
		Below threshold	Above threshold		Below threshold	Above threshold
$P_{t-1}^{elec}$	0.575*** (0.072)	0.218 (0.166)	0.607*** (0.052)	0.730*** (0.043)	0.641*** (0.044)	0.794*** (0.076)
$P_t^{gas}$	0.215*** (0.050)	0.707*** (0.178)	0.174*** (0.045)	0.113*** (0.042)	0.205*** (0.039)	0.045 (0.075)
$P_t^{coal}$	-0.031 (0.048)	-0.780* (0.406)	-0.031 (0.049)	-0.033 (0.045)	-0.197*** (0.051)	0.088 (0.064)
$P_t^{carbon}$	0.190*** (0.046)	-0.325 (0.250)	0.224*** (0.055)	0.182*** (0.042)	0.245*** (0.053)	0.048 (0.063)
$T^{level}$	-0.006*** (0.001)	-0.025** (0.0098)	-0.006*** (0.001)	-0.016*** (0.003)	-0.025*** (0.003)	-0.005 (0.007)
$(T^{level})^2$	0.0002*** (0.000)	0.0024* (0.0011)	0.0002*** (0.000)	0.0004*** (0.000)	0.0007*** (0.000)	0.000 (0.000)
$cons$	0.767*** (0.120)	3.429*** (0.920)	0.671*** (0.080)	0.597*** (0.073)	0.889*** (0.151)	0.603*** (0.144)
$season_2$	-0.135*** (0.019)	-0.036 (0.040)	-0.144*** (0.019)	0.168*** (0.016)	-0.134*** (0.017)	-0.201*** (0.028)
$season_3$	-0.138*** (0.020)	-0.040 (0.043)	-0.147*** (0.020)	0.167*** (0.017)	-0.131*** (0.018)	-0.200*** (0.029)
$season_4$	-0.184*** (0.025)	-0.154 (0.124)	-0.184*** (0.020)	0.195*** (0.016)	-0.166*** (0.020)	-0.219*** (0.027)
$season_5$	-0.314*** (0.020)	-0.182*** (0.046)	-0.323*** (0.020)	0.314*** (0.015)	-0.277*** (0.017)	-0.353*** (0.026)
$R^2$	0.8128	0.4854	0.8475	0.8808	0.8316	0.8554
$Joint R^2$		0.8225			0.8859	
Homoskedasticity (p-value)	0.014	0.069		0.000	0.000	

Note: Standard errors are in ( ) ; values in [.] represent the 95% confidence interval of the estimated threshold ; \*, \*\* and \*\*\* refer respectively to the 10%, 5% and 1% significance levels. The Joint R-squared is calculated from the residuals of model (4).

from each other. Neither of them appear in the 95% confidence interval of the other price threshold.

A detailed analysis of the results in Table (2) highlights the speculative behavior of French electricity producers on the emissions permit market. Speculation, as defined by David Newbery,<sup>5</sup> is the purchase (or temporary sale) of goods for later resale (repurchase), rather than use, in the hope of profiting from the intervening price changes. When the price of emission permits is low (below the threshold of 14.94 €/ton), French electricity producers expect it to rise. They buy permits in order to speculate and hedge the carbon risk-market by including the price of carbon allowance in their electricity-generation cost function: a rise of 1% in the emission-permit price results in 0.24% higher French day-ahead electricity prices. Hedging here is undertaken to reduce the risks arising from risky speculative activity. When the carbon spot price exceeds the threshold, it is no longer included in the cost function of electricity generation. At that time, French electricity producers sell their permits and take their profits.

The behavior of German electricity producers is the opposite of their French counterparts and does not reveal any speculative conduct. When the emission-permit price is low (below the threshold of 12.57 €/ton), German electricity producers do not include the price of emission permits in their production cost function. When the carbon price exceeds the threshold, it is a determinant of German electricity prices: 1% higher carbon prices result in 0.22% higher day-ahead electricity prices.

## 4 Conclusion

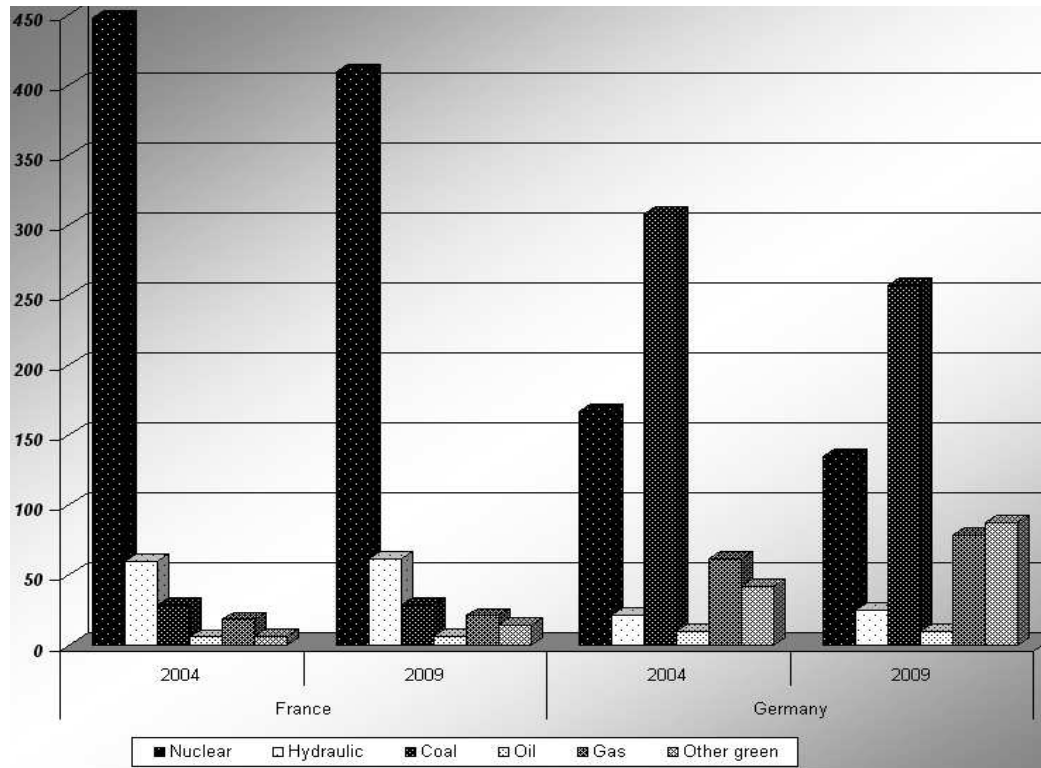
In this paper we have estimated the relationship between electricity prices and the prices of both the primary energies used in electricity generation and carbon dioxide emission permits in both France and Germany, using a nonlinear threshold model. The results reveal heterogeneity in the response of the electricity-generation sector to carbon constraints. French electricity producers behave speculatively, while their German counterparts do not. This behavior reflects the composition of the French energy mix. The predominance of non-fossil energy sources in France means that there is less need to use emission permits, and so greater opportunity for speculation in the market for emission allowances.

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<sup>5</sup>See the article on "Futures markets, hedging and speculation" in "The New Palgrave Dictionary of Economics".

## A APPENDICES

### A.1 Energy mixes in France and Germany



The French and German energy mix in 2004 & 2009 (source: IEA)

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